

STATE OF CALIFORNIA  
DEPARTMENT OF PUBLIC WORKS  
DIVISION OF HIGHWAYS

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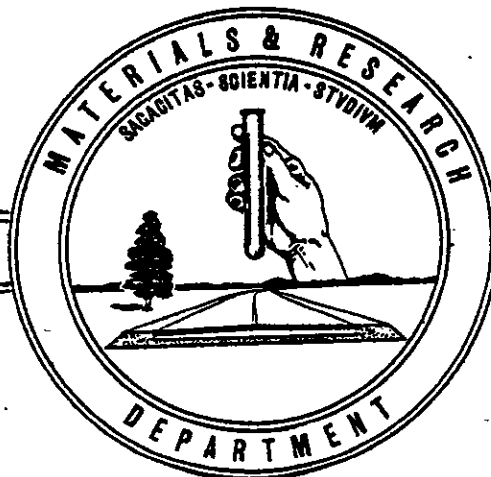


FINAL REPORT  
OF FULL SCALE DYNAMIC TESTS  
OF BRIDGE CURBS AND RAILS

57-03

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August 30, 1957



57-03

State of California  
Department of Public Works  
Division of Highways  
Materials and Research Department

August 30, 1957

Lab. Order No. 88-R-6012  
W. O. 53-13NN11  
W. O. 55-13NN11

Mr. F. W. Panhorst  
Assistant State Highway Engineer  
Bridge Department  
Sacramento, California

Dear Sir:

Submitted for your consideration is:

FINAL REPORT  
OF FULL SCALE DYNAMIC TESTS  
OF BRIDGE CURBS AND RAILS

Study made by . . . . . Structural Materials Section  
Under general direction of . . . . . J. L. Beaton  
Work supervised by . . . . . H. A. Peterson  
Report prepared by . . . . . R. N. Field and J. L. Beaton

Very truly yours,



F. N. Hveem  
Materials and Research Engineer

RNF:mw  
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District Engineers

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FINAL REPORT  
OF FULL SCALE DYNAMIC TESTS OF BRIDGE CURBS AND RAILS

SYNOPSIS

A great deal of design and study has gone into the subject of curbs and rails for highway bridge structures. These efforts have been primarily directed toward improving the strength, aesthetics, and visibility of the curb and rail unit. Prior to January 1953 investigations of the dynamic behavior of such units had consisted principally of on-the-spot investigations and study of reports concerning accidents involving edge barriers on bridges. Full scale dynamic tests of bridge curbs and rails were commenced by the Materials and Research Department in January 1953 and continued intermittently through the years 1953, 1954, and 1955.

Two progress reports have been issued involving various designs of bridge curbs and bridge rails subjected to oblique collisions by standard stock model automobiles. The first report, titled "Roadway Barrier Curb Investigations", was transmitted to the Bridge Department on December 31, 1953. The second, titled "Full Scale Tests of Concrete Bridge Rails Subjected to Automobile Impacts", was transmitted to the Bridge Department on December 19, 1955, and was also presented as a paper to the 35th Annual Meeting of the Highway Research Board on January 20, 1956.

This report is a complete compilation and analysis of the information accumulated during the entire series of tests involving the bridge curbs and rails.

## INTRODUCTION

This study concerning the dynamics of highway bridge rails and curbs was initiated by the joint efforts of the Bridge and Planning Departments by two actions. The first was on August 18, 1952, under Work Authorization 53-13NN11 and the second in September 1954 under Work Authorization 55-13NN11. The original object of this study was stated thus: ".....to determine the most efficient type of bridge curb or rail." This objective was interpreted to mean that only the efficiency of the curb and/or rail as a physical barrier was to be determined; in other words, the ability of the roadside unit to retain an automobile on the structure was to be rated. It was further considered that the most efficient barrier unit would be one which, under the conditions of an oblique collision, would (1) retain the vehicle on the roadway with (2) a minimum amount of damage to the impacting vehicle and (3) result in a deflection angle that would minimize the possibility of collision between the impacting vehicle and other vehicles traveling in the same direction and on the same roadway.

Organization of test procedure required a definition of a curb and rail. The American Association of State Highway Officials in the Standard Specifications for Highway Bridges states that a bridge railing must be not less than 2'3" nor more than 3'6" above the adjacent roadway. It further states that a bridge curb in an urban area must be not less than 7" high and in a rural area must be not less than 9" high. A strict dimensional definition was not practical, since bridge railings less than 2'3" in height were to be tested. The following definitions were therefore selected for this study:

**Bridge Curb:** An obstruction provided to delineate the edge of the roadbed and to discourage a vehicle from leaving the pavement.

**Bridge Rail:** An obstruction provided along the edge of the roadway to prevent automobiles from leaving the side of the structure.

From a Traffic Department analysis of accidents involving roadside barriers, it was determined that the majority of collisions with roadside barriers occur between 15° and 20° angle of collision. It was first decided to use test collision angles of from 5° to 30° in increments of 5°. However, experience from 1953 tests indicated only a slight difference in vehicle reactions between the 5° and 10° angle of collision. Vehicle reactions at 25° were similar to those at 20° and at 30°. Therefore, the tests were conducted using angles of collision of 7½°, 15°, 20°, and 30°. Significantly collision angles between 15° and 20° seemed critical concerning vehicle reactions.

Tests showed that in most cases an automobile approaching at an angle of  $15^{\circ}$  would be deflected from a curb, while an automobile approaching from a  $20^{\circ}$  angle would mount the curb. Also, a large concentration of property damage accidents occurs between these collision angles.

## CONCLUSIONS

The results of this series of tests can be divided into three categories: general (factors common to any type of continuous roadside barrier), bridge curbs (factors pertinent to curbs only), and bridge rails (factors pertinent to rails only).

### GENERAL

1. A moving vehicle, when colliding with a roadside barrier, is either (a) deflected back into the line of traffic, or (b) permitted to pass over the barrier unit.
  - a. When the vehicle is deflected, the angle of deflection, which is normally substantially less than the angle of collision, is dependent upon:
    1. The angle of collision.
    2. The amount of energy absorbed by vehicular damage during collision.
    3. The drag of the damaged portion of the vehicle.
  - b. When passing over a barrier, a vehicle will dynamically rise higher than the mere height of the barrier (see Figures 14 through 16). The height and length of jump of a vehicle was observed to be dependent primarily upon the mass and velocity of the vehicle and the height of the curb. The jump is dependent partly upon the failure or non-failure of the front wheel (affected by the construction of the particular front wheel suspension) during the initial collision.
2. The final velocity of a deflected vehicle after an oblique impact with an obstruction is higher when the material of the obstruction is steel than when the material is concrete. The deceleration due to collision appears to be related directly to the coefficient of friction established between the vehicle contact material (usually the tire) and the curb material. The

velocity of a deflected vehicle is also markedly decreased by a sharp undercut at the base of a barrier curb. The undercut must be just high enough to contain the bulge of a tire (see Figure 1C).

### BRIDGE CURBS

1. The effectiveness of a curb as a barrier to obliquely colliding vehicles varies directly with curb height and inversely with the angle of collision.
2. The deceleration of a deflected vehicle is more with an undercut curb than with a curb without an undercut. The upper edge of the undercut should be as sharp as is compatible with good construction practice.
3. A curb with a sharp top leading edge in lieu of a rounded lip is inefficient since the sharp edge tends to "bite" the rim of an automobile wheel. This in turn facilitates the dynamic rise of the wheel off the roadway surface. Such behavior is true of either concrete or steel and is especially noticeable when a steel channel is used as a curb. (See Figure 3). A slight back slope to the curb (not more than 1:4) alleviates this action. A rounded upper lip reduces it materially.
4. When considering all factors of barrier effectiveness, especially velocity and deflection angle of the vehicle after impact, the undercut concrete curb is the most efficient type.
5. When attempting to balance the advantage gained from height of curb as a barrier against the disadvantage of the increase in dynamic jump as effected by height, it appears that a curb 10" high is the most efficient.
6. Tests on barrier rails indicate that an obstruction as high as 1'9" will not present an effective physical barrier to automobiles colliding with it at high angles of collision (20° to 30°) and at impact speeds of 45 to 60 mph.
7. The results of these tests indicate that the proposed curb design shown in Figure 1C should result in the most efficient bridge curb design.



## BRIDGE RAILING

1. If a concrete barrier rail is constructed on a plane flush with the pavement, without a curb between it and the traveled way, the rail should have a height of not less than 2'3" to be effective as a barrier against automobiles (see Figure 1A).
2. If a rubbing curb is placed at the base of a bridge rail primarily to minimize the damage to a car driven too closely to the rail, such a curb should have a horizontal projection from the rail of between 3 inches and 5 inches. A rubbing curb projecting more than 5 inches will probably act as a lifting fulcrum during high speed collisions.
3. Bridge rails used in combination with a curb, set back greater than 5 inches, must be higher than bridge rails used without a curb. Analysis of the "jump curves" (Figures 14 through 16) indicates that the basic rail height (27" above curb) should be increased by 5 inches for each 12 inches of setback from the curb face to a maximum height of 48 inches (see Figure 1B).

## OUTLINE OF TESTS

### 1953 CURB TESTS

This preliminary phase of the program was discussed completely in the report (Reference 1) dated December 31, 1953.

In 1953 eleven different designs of roadway curbing were tested, each represented by a section 100 feet long. These curbs are identified in Figure 2. All of the 1953 curbs were constructed of concrete except Curb VI-M. The three heights of curbing tested were 6", 9", and 12".

The 1953 test curb installation was 500 feet long and 3 feet wide. Ten different curbs were formed, five on each side. Wood forms were used (except for Curb VI-M, Figure 2) and the concrete was placed directly on the airport bituminous pavement surface. The curbs resisted sliding without the use of dowels. A metal form was used to construct Curb VI. This form was later reinstalled to serve as a metal facing (Curb VI-M) and additional comparative tests were made to determine the differences between concrete and metal as a curb surface.

The bituminous surface of the approach runway was similar in texture to an average plant-mix surfacing.

The test automobile driven by a test driver was a 1949 Ford sedan. The vehicle had a wheel base of 114", tire size of 6:00 x 16, and total weight of approximately 3224 pounds. Bracing similar to that used in a hardtop racing car was constructed around the driver's seat. A safety belt was installed and the front seat tied down securely. The engine was tied to the frame to keep the clutch from disengaging when the car struck the curb. A 2" structural steel angle was welded across the frame under the driver's seat to protect the undercarriage from damage when the car mounted the curb.

A special calibrated speedometer was installed in the car. The contact speed of each collision was photographed by a 35 mm still camera mounted on the vehicle safety frame.

The outer sides of the tires were painted with a cold water paint, the front tires red and the rear tires green. This paint rubbed off readily onto the curb showing the tire contact area and roughly the height of the climb. The only other change made to the test car was the removal of the back seat. During the test numerous "A" frames, tie rods, and wheels were replaced.

Immediately following each collision, data was recorded of the mounting and contact characteristics of each wheel, deflection angle of the post-collision travel, and damage to the vehicle. In addition, a laboratory analysis was made of motion pictures taken during each test. The results of this

test showed the value of curb face slope and undercut but indicated the need for additional information on the effect of curb height and material.

### 1955 CURB TEST

In early 1955 additional tests were conducted so that specific recommendations could be made for the design of more efficient barrier curbs. These studies were performed on the four designs of barrier curbs indicated by the 1953 test to be the most promising. These four designs were tested at 9", 10", 11", and 12" heights (see Figure 3).

Radio remote control of the test vehicle replaced the test driver used in previous experiments.

The site for this experiment, both in 1953 and in 1955, was the west runway of the Sacramento County Airport located about 25 miles south of Sacramento. The trial barrier curbs were positioned about midway along the east edge of the west runway permitting about 1500 feet of runway approach to the rails from either direction

For this series of tests 30 feet of barrier curb was used for each crash in lieu of the 100 feet employed in 1953, since the shorter length had been previously determined adequate for test purposes.

The test barrier curbs were prefabricated to exact dimensions in ten-foot sections. Twenty-eight day test cylinders indicated the concrete to vary in strength from 2700 to 5800 psi for all test units. Intermediate grade reinforcing steel was used throughout.

During the test collision period the precast barrier curb units were bolted securely to an anchor block by six 1" bolts. The anchor block was a continuous section of concrete 18" deep, 36" wide, and 30 feet long. General details of test curb assembly are shown by the photographs in Figures 17 and 18.

The arrangement of the test site and the position of various pieces of equipment used during the test are shown in Figure 4.

The following five automobiles were used in 1955 as test cars: one 1949 Ford 4-door sedan, three 1949 Ford 2-door sedans, and one 1946 Buick 4-door sedan. The Fords were equipped with 6:00 x 16 tires and the Buick with 7:60 x 15 tires. Each of the cars was a standard stock model, slightly modified to provide radio remote control. Minor structural alterations were made in order to minimize repairs during this portion of the barrier test program. The front end frame members were stiffened by welding an additional 1/4" side plate to each side of the front 2 feet

of the frame and by welding a 2" x 2" structural steel angle across the frame directly under the front seat (Figure 20). This duplicated structural alterations made in the 1953 tests. In addition the engine was snubbed tightly to the frame with cable to keep the clutch from disengaging when the car struck the curb. A comparison of actions with and without this bracing and alteration during the 1955 barrier curb tests revealed no appreciable external change in action.

Since the tests required attainment of high speeds in a relatively short accelerating space of 1500 feet, the engine of each car was completely tuned up and muffler, air filter, and fan belt were removed.

It is considered by all participants in the experiments that the 1955 method incorporating radio remote control, adjustable curb mounts, and high speed photography was more efficient than the 1953 test method for the following reasons:

1. The radio remote control mechanism permitted higher speed collisions and eliminated nervous human reaction to approaching or colliding with a solid barrier. The test car in each case was allowed to travel through collision without any adjustment or turning of the steering wheel or application of brakes. The radio remote control system used in the 1955 tests is explained in detail in Reference 2.
2. The movable or adjustable curb units were more efficient than the permanently cast curbs used in 1953, since they eliminated the necessity of moving any control grid or camera installation from one curb to another, and the height could be adjusted with a minimum of effort (Figure 18).
3. The high speed cinephotography employed during the 1955 crash enabled many important observations which were missed during the 1953 program where standard speed cine cameras had been used.

A comparison of the barrier curbs tested in 1955 indicates the following:

1. All 4 designs tested at the 9" height were mounted by the impacting wheel when struck between 15° and 20° at the relatively slow speed of 30 mph.
2. Height is the controlling factor of any structurally sound curb. The tables (Figures 10 through 13) show that increased speeds were necessary to cause mounting of curbs higher than 9".

3. The deflection action of the pipe curb (Curb C, Figure 3) was superior to the other type curbs. Speeds of 45 mph and higher were required to mount this type of curb.
4. Curbs B and C (the composite and pipe curbs) of 10" height were satisfactory at the flatter angles. At speeds of 60 mph these curbs were still effective in deflecting the test vehicles back onto the traveled way.

The test results and the motion pictures of the various tests disclose the following factors to be of primary importance in curb design, both for reducing damage to the car or curb and for increasing human safety:

1. Height of curb.
2. Materials used in the construction.
3. Geometric design.

## BARRIER CURB TEST DISCUSSION

### HEIGHT OF CURB

These tests prove that the higher the barrier the more likely it is to stop a moving object.

The height of a barrier curb for vehicles on the highway is dependent upon the physical size of the object it must stop or deflect. The 6:00 x 16 tires on older passenger automobiles are approximately 28" in outside diameter. The 1953 and 1955 tests showed that an increase in height of one or two inches over a 9" high design of barrier curbing has a marked effect on the ability of the curbing to deflect these automobiles.

An increase in height of a barrier curb reduces the wheel rim and tire action of "riding up" or "biting" for most of the curbs tested, and only major differences in shape and materials can alleviate such action when the heights remain constant.

In 1953 only two heights of barrier curb were tested. Analysis of this series of test data revealed that the 12" heights were much more efficient as a barrier than any of the 9" heights tested, regardless of shape. Therefore, in 1955 those curb designs which had shown promise in 1953 and a composite design were tested at heights of 9", 10", 11", and 12". The results, shown on Figures 10 through 13, indicate the increase in speed necessary to mount the curb at each height.

A series of "dynamic jump curves" (Figures 14 through 16) was developed from cine films of vehicles which mounted and passed over the curb (the motion of the vehicle frame nearest the colliding wheel was traced from the pictures). These curves, which show the height of rise of the vehicle at various distances after collision with the barrier curb can be correlated with the action of the vehicles during collision studies of bridge rail and curb combinations. During the bridge railing tests (Figures 5 through 9), it was determined that the position of the frame at its collision point with the barrier is critical.

The "jump curves" illustrate that when a wheel first starts to mount a curb, the wheel deforms with little rise in the car. The wheel later recovers, thus helping to raise the car during the general upward flight after mounting the curb. (See cine film strip reproduction, Figure 19).

The curves also illustrate that the velocity of the vehicle is a primary factor affecting the height and length of the jump after a vehicle mounts a curb. The height of the curb and the angle of collision also have a marked effect. The shape and material of the curb influence whether or not the car mounts the curb but seem to have little effect on the height or length of jump once the mounting is accomplished.



## MATERIALS

Of the many materials available for use as barrier curbs, concrete has been the most universally employed. Many types of metals have been used, and there are others which could be used. In the 1955 tests, steel pipe, steel channel, and a 3" radius steel armor on concrete were used. The pipe proved more satisfactory as a barrier than did the steel channels or the 3" radius armor. The poor performance of the steel channel was due to the sharp upper lip of the channel, which bit into the rim and raised the car (Curb D, Figure 13). A similar raising action occurred due to the exposed concrete face when the rounded steel armor (Curb B) was used. Rubber tires tend to grip the concrete below the lip making this type curb more readily mountable than the steel pipe curb.

The tests indicate that steel pipe curbs (Curb VI-M or Curb C of 1953 and 1955 respectively) are more effective than concrete curbs in deflecting a vehicle at high impact speeds. However, very little deceleration of the vehicle after impact is accomplished by the steel curbs. In contrast the best concrete curb of 1953 and 1955 design (Curb Type 5 and Curb A respectively) tends to slow down a vehicle at the same time that it deflects it. This deceleration is apparently caused by increased friction between the vehicle contact materials and the concrete.

The individual deflection actions of steel and concrete may be utilized according to the result desired at specific locations.

## GEOMETRIC DESIGN (SHAPE)

The vertical barrier curb has in the past served the limited function of presenting a visible barrier which discouraged a driver from deliberately leaving the roadway. In addition to this previous function, a bridge curb must now present as positive a barrier as possible to a high speed vehicle at flat angles of approach. It is also desirable that it be self-cleaning. Tests indicate that these two requirements can be met in one basic shape with the proper selection of height.

From available test data it is apparent that an undercut curbing is desirable in the majority of installations. An undercut of the proper design does not allow the tire sufficient contact to permit the wheel to mount the curb. The undercut of the curb tends to drag on the rotating tire, retarding its movement and holding the wheel down on the road surface by means of the friction and mechanical action created by the rounded tire which squeezes under the protruding face of the curb. Scupper openings in the undercut permit the roadway to be self-cleaning of debris.

In combination with the undercut, a batter is necessary. The angle of batter should not allow the tire or rim to mount the

curb. A batter of 2" in a vertical height of 9" (Figure 2, Curb III) was shown to be satisfactory in the tests run in 1953. This design was made of concrete with a 1" radius along the exposed upper lip. The use of metal curbing should not affect this slope requirement. The leading edge should have at least 1" radius, whether the material is concrete or metal.

The smooth rounded surface acts as an effective deflector providing the material is steel. A rounded concrete nose does not function efficiently (Figure 2, Curb VI).



## SUMMARY

A barrier curb design which incorporates all the features proven the most desirable in the testing program is shown in Figure 1C. It is recommended that the material employed be either concrete, steel armored concrete, or steel, depending on location and service.

Several important factors were noted during the tests made in 1953 and 1955. These are given below.

1. When it is a prerequisite that a barrier curb keep as many vehicles from mounting the curb as possible, the curb height should be at least 10".
2. When practical, an undercut type of barrier curb should be employed.
3. The choice of materials should be made with consideration given to the action desired.
  - a. The smooth tough surface of steel exerts less friction on a wheel and tire than concrete; therefore, the steel surface tends to be more efficient as a barrier but deflects the cars back into the traveled way with little loss in speed. A sharp upper lip or bend in a steel curb must be avoided, because they tend to allow "biting" or "grabbing" of the tire rim.
  - b. Concrete curb surfaces should be a smooth rubbed surface finish (Class 2, California Division of Highways). Friction on concrete will be more pronounced than on smooth steel surfaces and will help decelerate the car. However, the concrete surface finish must not be so rough that it results in the vehicle riding up the face of the curb. The same other factors regarding sharp lip or changes in section must be respected in concrete curbs the same as in steel.
4. The effect on the driver or passengers in any vehicle striking a curb is important. During this series of oblique collisions with bridge railings, a study of potential passenger injuries was conducted by the University of

California. A report on this phase of the project by the Institute of Transportation and Traffic Engineering (Reference 3) states:

".....Moderately high-speed oblique impacts were characterized by relatively low longitudinal decelerations which last approximately 100 milliseconds accompanied by very high lateral decelerations which last for no more than 20 milliseconds. When these lateral decelerations are of very short duration, and for those cases when the car doors remain closed, they tend to be more of a hazard in disorienting the motorist (thereby leading to loss of control of the car) than by directly producing injury."

From this cooperative portion of the barrier curb and bridge rail tests, it was evident that loss of control of the vehicle can occur during impact. If the driver is disoriented, he will have less opportunity to control the direction of travel and speed. A curb that will result in the smoothest barrier action possible therefore seems desirable.

The design suggested in this report is derived from observations made during the actual testing program and analysis of recorded data. No actual tests have been performed on the proposed design, but it is considered that the testing program did prove that this proposed design would be more satisfactory than any of the types tested in attempting to achieve the barrier action that would cause least disorientation of the motorist.

5. The bridge rail tests performed in 1955 are here reported but briefly. One important observation should be noted. This test pertains only to concrete rails and probably should not be used to evaluate steel rail. The elastic characteristics of steel rails would probably result in a different type of dynamic action than that encountered in a collision with a rigid concrete rail. The heavier a steel rail, the closer its action will be to a concrete rail.

### FUTURE STUDY PROPOSALS

Future full scale studies should include investigation of the following:

1. The proposed barrier curb design, Figure 1C, should be tested at several heights and speeds. The final design has not been tested by actual collisions and a factual report of its efficiency cannot yet be made.
2. The several types of steel guard rail now used as bridge railing should be tested under full scale collision. Since steel rails were not tested during the bridge rail test series, a comparison or correlation between steel and concrete is desirable.
3. The current size 6:70 x 15 wheels should be used in further experiments. Larger wheels, such as those used on the school bus type of vehicle, should also be used.

The radio control system, cameras, and other test equipment used in these tests have been retained intact for use in future tests. The anchor block is still in place on the Sacramento County Airport runway.

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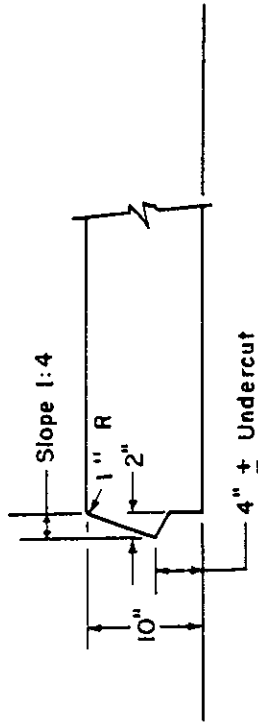
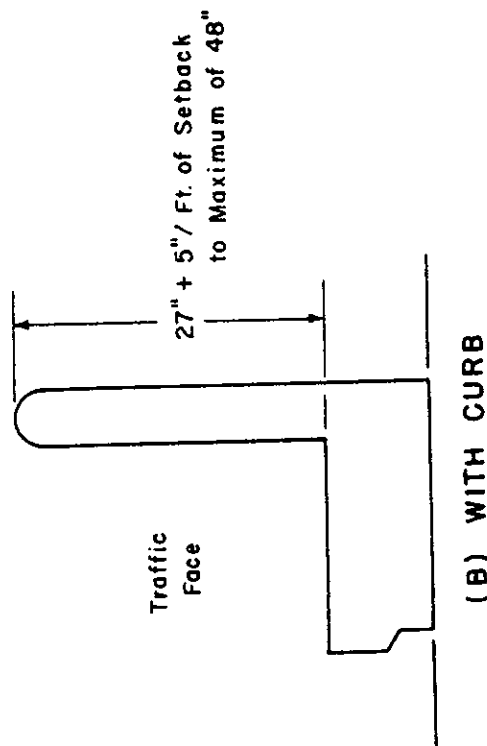
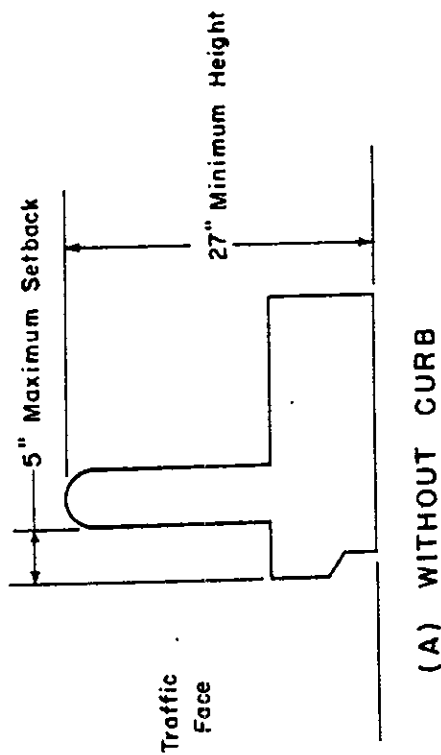
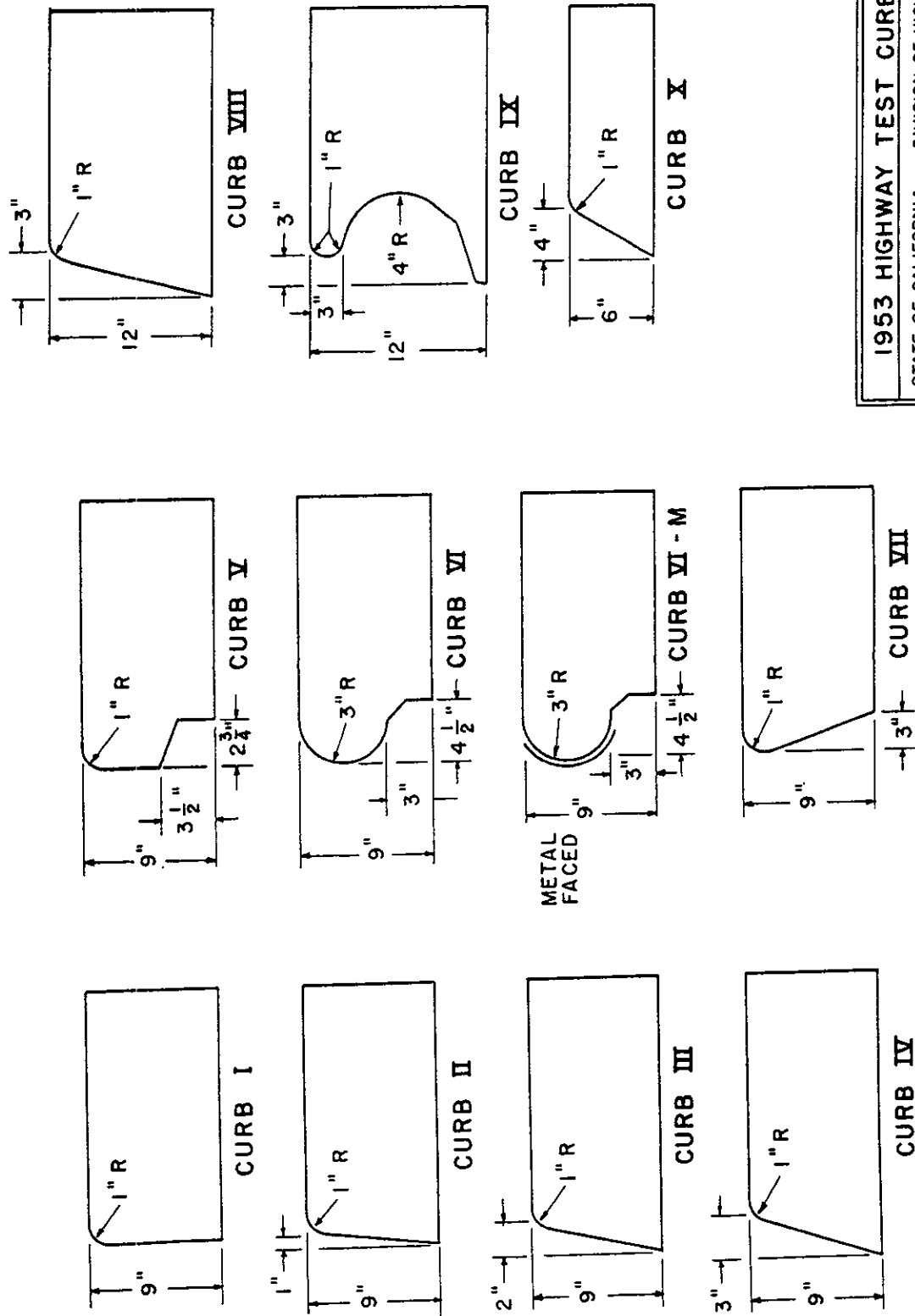


Figure 1

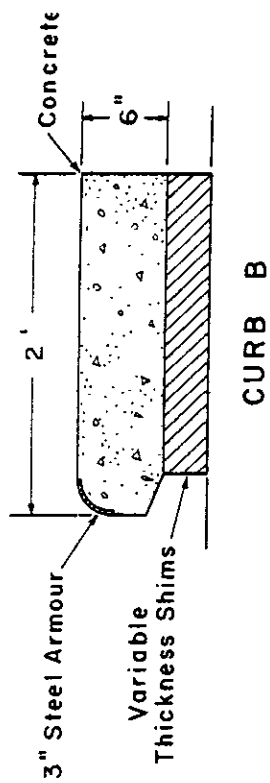
<b>CURB &amp; RAIL RECOMMENDATIONS</b>
STATE OF CALIFORNIA — DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPARTMENT

BRIDGE BARRIER RAILS

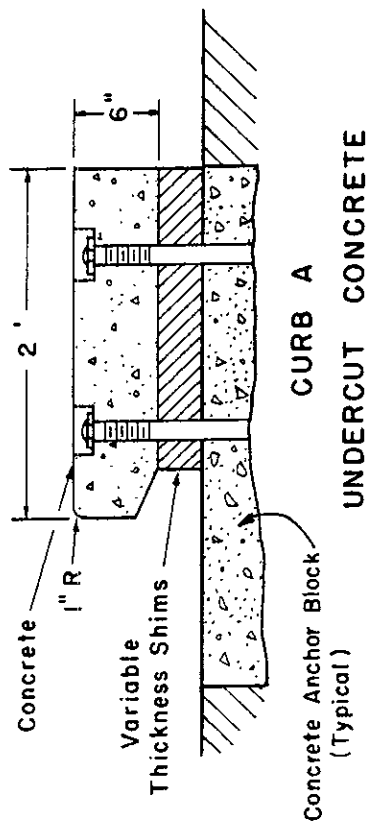
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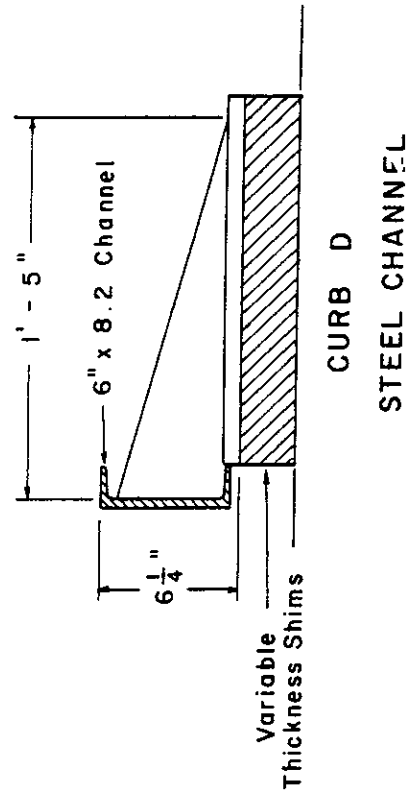
1953 HIGHWAY TEST CURBS  
STATE OF CALIFORNIA — DIVISION OF HIGHWAYS  
MATERIALS & RESEARCH DEPARTMENT



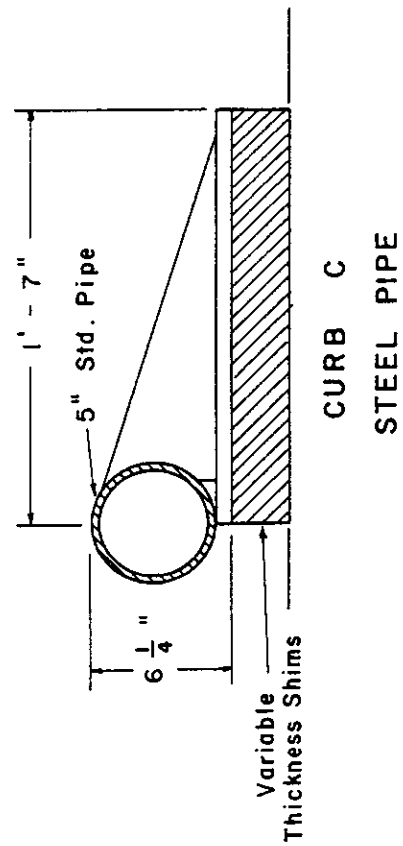
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UNDERCUT CONCRETE



STEEL CHANNEL



STEEL PIPE

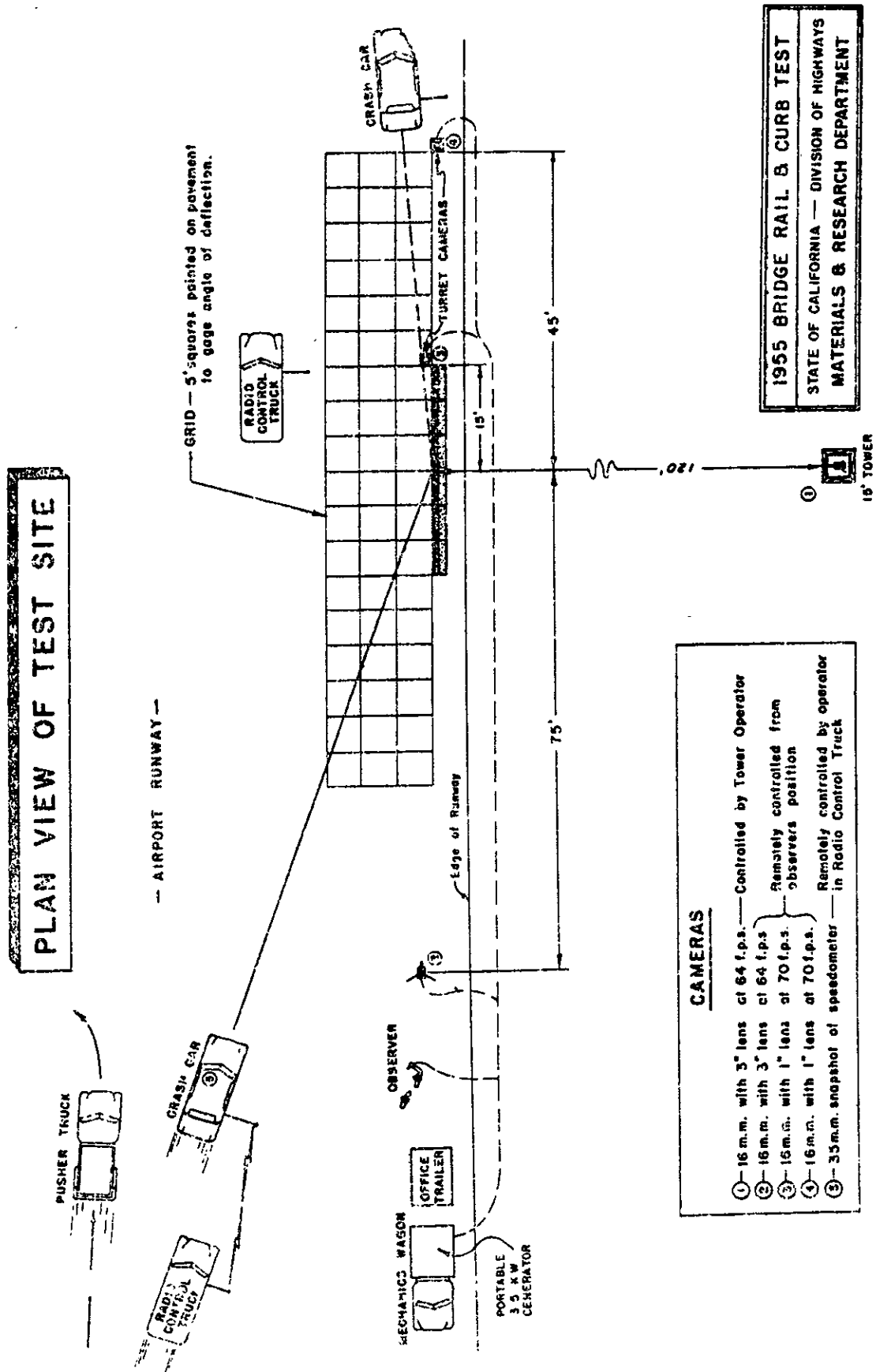
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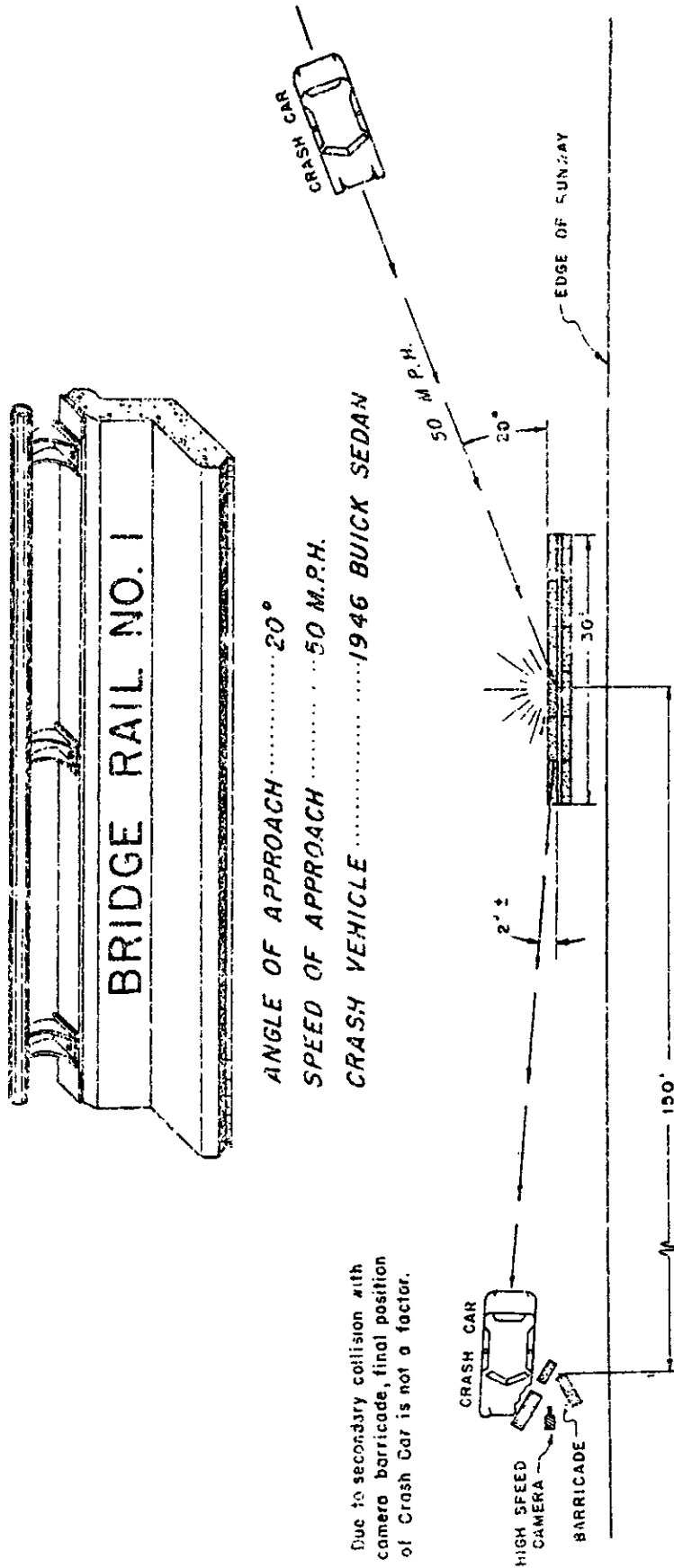
1955 BARRIER CURB TEST

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**Figure 4**

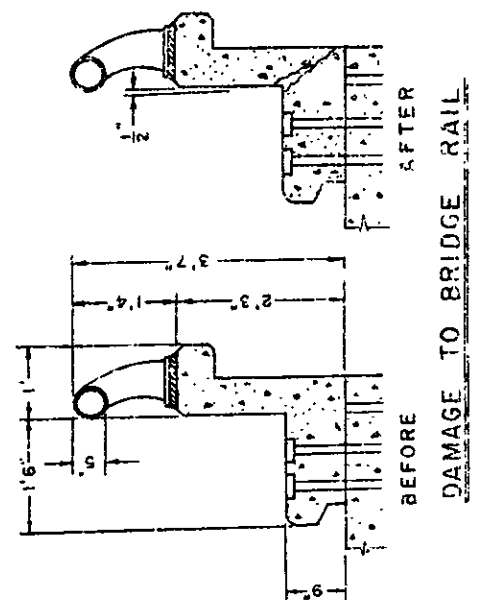




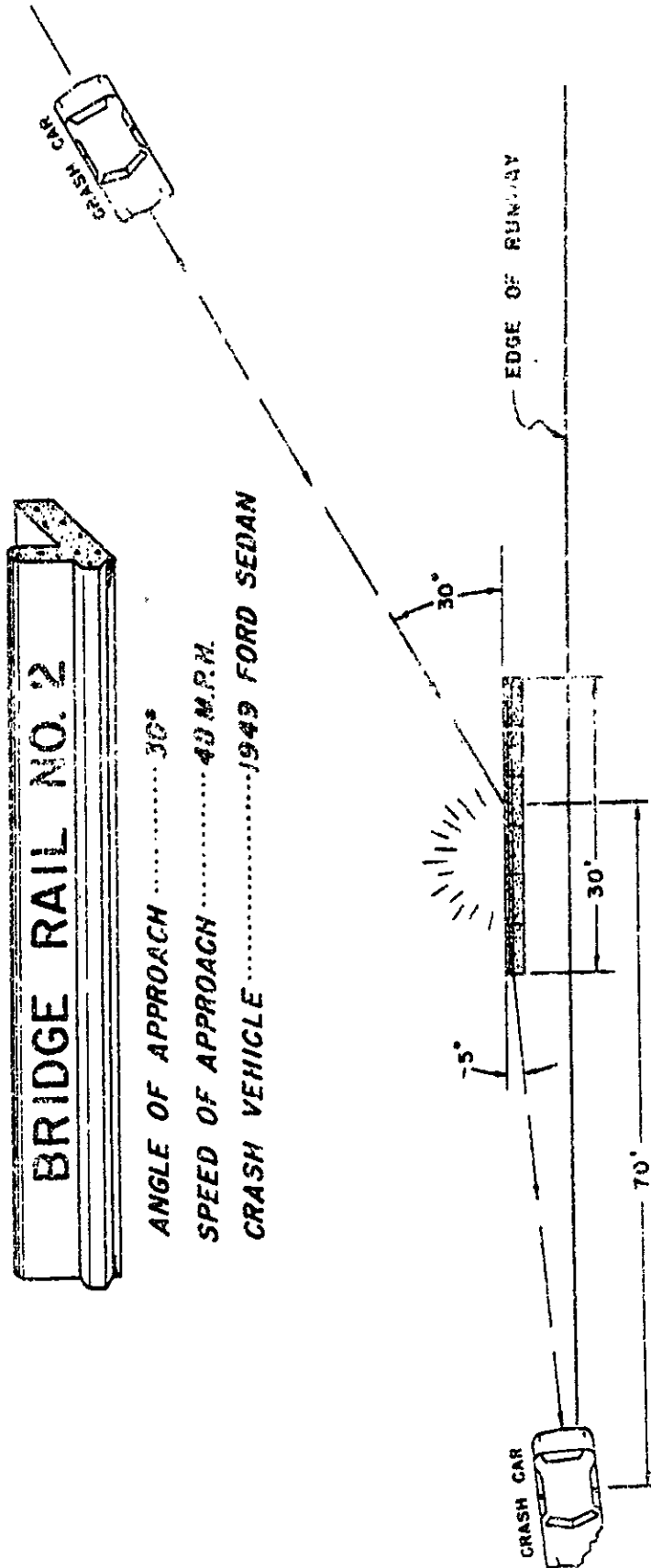
Due to secondary collision with camera barricade, final position of Crash Car is not a factor.

### TEST RESULTS

The crash vehicle was deflected by the bridge rail at an angle of approximately 2°. The collision caused only a slight hesitation in the cars forward travel with minor tipping action noticeable as the car deflected along and then away from the bridge rail. The car mounted the 9" curb readily and then slid along the rail for 10' before leaving the Bridge Rail. It appeared that the pipe rail prevented excessive tipping of the car.



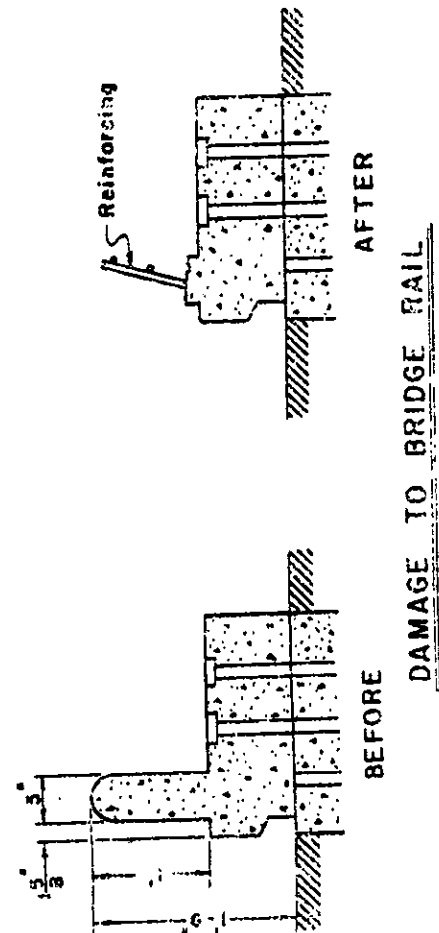
1955 BRIDGE RAIL & CURB TEST  
STATE OF CALIFORNIA — DIVISION OF HIGHWAYS  
MATERIALS & RESEARCH DEPARTMENT



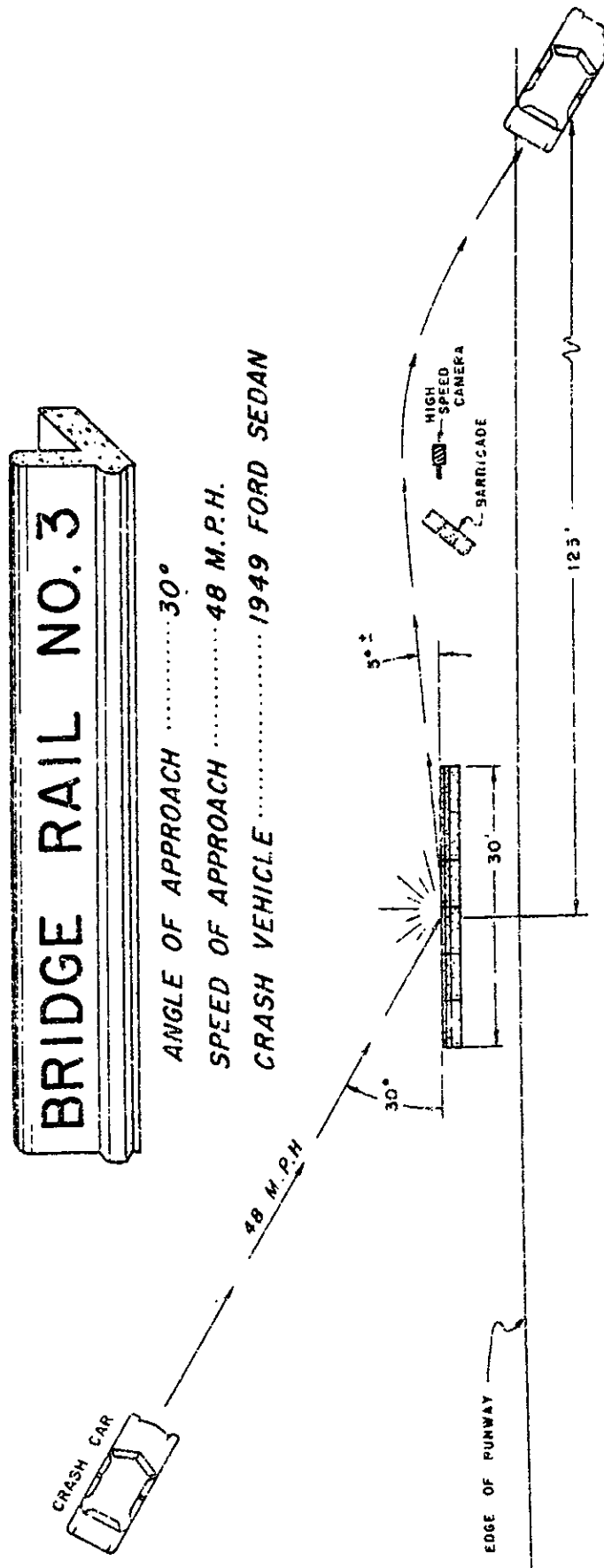
PLAN VIEW

TEST RESULTS

The crash vehicle broke out 9' of the bridge rail on the initial collision. This allowed the car to straddle the rail, and then continue on through the rail at an exit angle of approximately -5°.

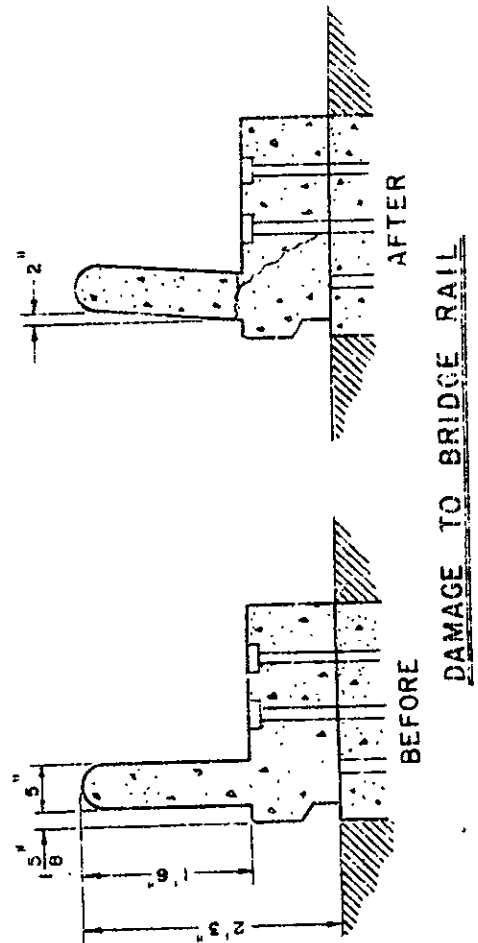


1955 BRIDGE RAIL & CURB TEST  
 STATE OF CALIFORNIA — DIVISION OF HIGHWAYS  
 MATERIALS & RESEARCH DEPARTMENT



### TEST RESULTS

The crash vehicle was deflected by the bridge rail at an angle of approximately 5°. The collision caused only a slight hesitation in the cars forward travel with minor tipping action noticeable as the car deflected away from the bridge rail.



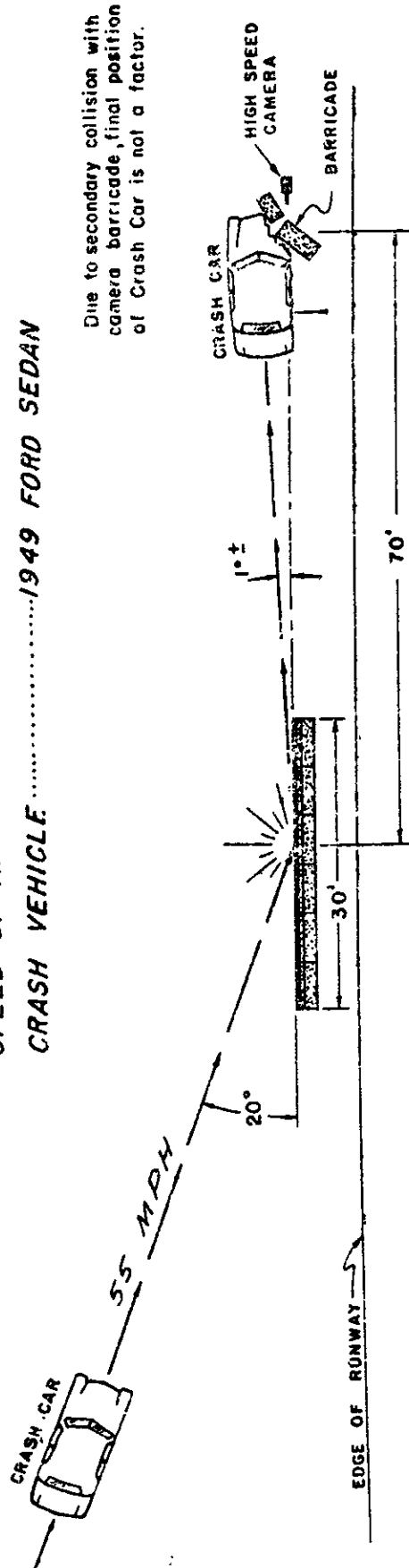
1955 BRIDGE RAIL & CURB TEST
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# BRIDGE RAIL NO. 3

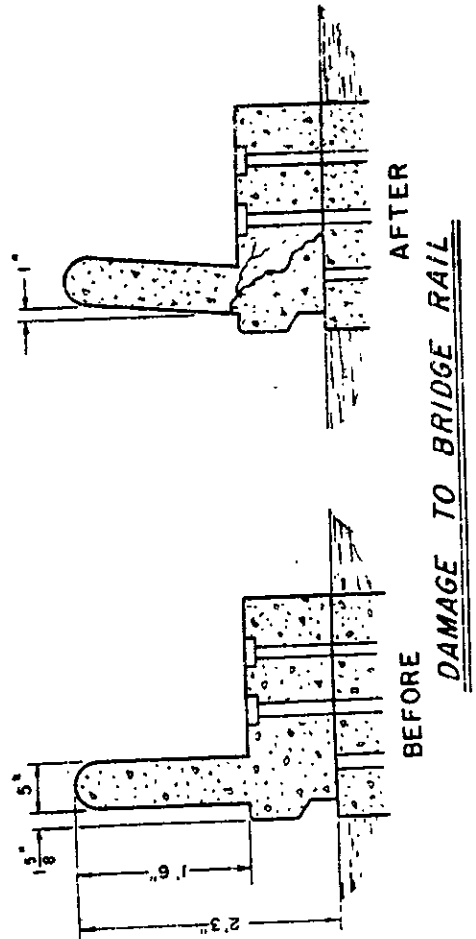
ANGLE OF APPROACH ..... 20°

SPEED OF APPROACH ..... 55 M.P.H.

CRASH VEHICLE ..... 1949 FORD SEDAN



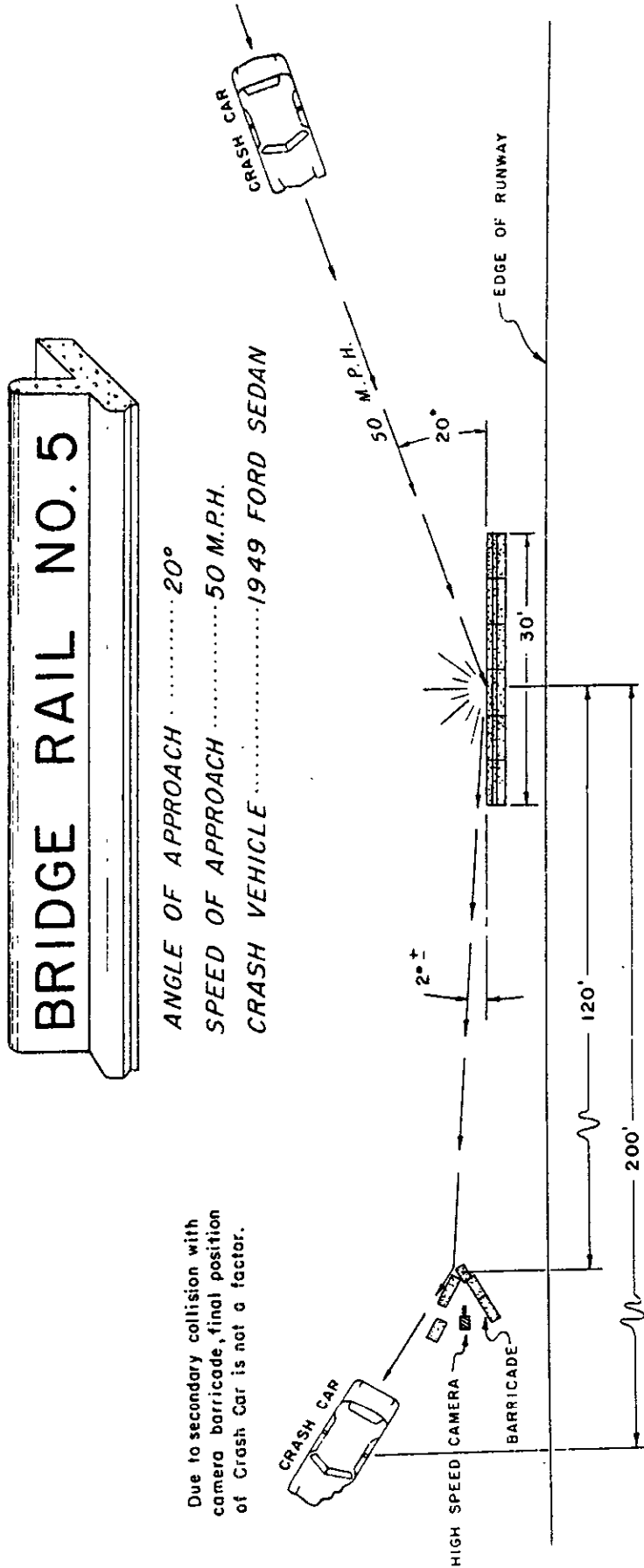
PLAN VIEW



## TEST RESULTS

The crash vehicle was deflected by the bridge rail at an angle of approximately 1°. The collision caused only a slight hesitation in the car's forward travel with minor tipping action noticeable as the car deflected away from the bridge rail.

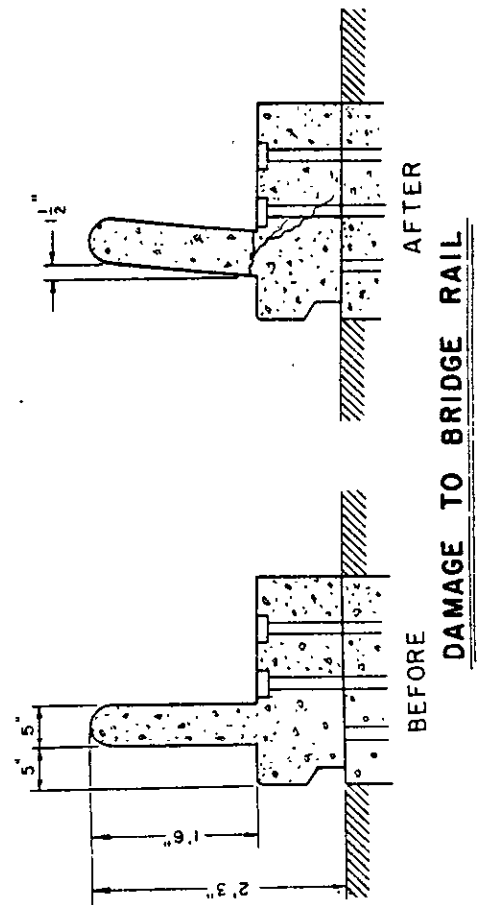
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PLAN VIEW

TEST RESULTS

The crash vehicle was deflected by the bridge rail at an angle of approximately 2°. The collision caused only a slight hesitation in the car's forward travel with minor tipping action noticeable as the car deflected away from the bridge rail.



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Figure 10

CURB HEIGHT (INCHES)	ANGLE (DEG.)	SPEED (M/H)	DEFL. (INCHES)	CLIMB (INCHES)	MOUNT	DAMAGE TO CAR	WHEEL CONTACT ON CURB (FT)		CURB CONTACT ON WHEEL (%)			
									FRONT		REAR	
							FRONT	REAR	TIRE	RIM	TIRE	RIM
9	7.5	60			F-R	MAJOR	6.5	4.0	40	40	30	30
9	15	15	R		F	MEDIUM	4.2	11.2	40	40	100	0
9	15	20		R-7	F	MAJOR	3.6	4.8+1.7	40	40	60	0
9	15	30			F-R	"	3.5	1.8	25	25	15	5
9	20	10			F-R	"	2.0	5.0	5	5	20	0
10	7.5	60			F-R	"	10.3	6.2	100	100	100	100
10	15	30	R	F-3		"	9.5	5.3	100	90	75	70
10	15	45			F-R	"	2.0	1.8	15	15	5	5
10	20	30			F-R	"	4.8	1.4	40	40	10	10
11	15	45			F-R	"	9.0	4.5	75	75	50	50
11	20	30			F-R	"	4.2	1.9	60	50	25	20
12	20	20	R	F-1		"	6.8	3.2	50	50	40	0
12	20	50			F-R	"	8.7	4.3	50	50	50	50

(F = Front R = Rear)

CURB A - 1955 Barrier Curb Test Data

Figure 11

CURB HEIGHT (INCHES)	ANGLE SPEED (M/H)	DEFL. (INCHES)	CLIMB (INCHES)	MOUNT	DAMAGE TO CAR	WHEEL CONTACT ON CURB (FT)		CURB CONTACT ON WHEEL (%)		
						FRONT	REAR	TIRE	RIM	REAR
9	7.5	60		F-R	MAJOR	6.3	7.3	50	30	30
9	15	20		F-R	"	2.9	2.4	50	30	0
9	15	20		F-R	"	2.0	2.0	20	0	0
9	15	30		F-R	"	3.0	1.8	30	15	10
9	20	30		F-R	"	2.5	2.7	30	15	10
10	7.5	60	F-R		"	14.6	11.2	100	100	100
10	15	30	F-R		"	11.3	5.7	75	60	75
10	15	45		F-R	"	3.4	2.2	20	20	20
10	20	30		F-R	"	3.5	2.3	40	40	20
11	15	45	F-R		"	3.4	2.2	20	20	20
11	15	60		F-R	"	6.0	3.0	25	25	25
11	20	30	R	F	"	2.3	1.2	20	20	20
11	15	45		F-R	"	6.0	4.0	60	50	20
12	20	40		F-R		6.9	3.7	50	50	40
12	20	40		F-R		4.2	2.4	100	20	20

(F = Front R = Rear)

CURB B - 1955 Barrier Curb Test Data



Figure 12

CURB HEIGHT (INCHES)	ANGLE (DEG.)	SPEED (M/H)	DEFL. (INCHES)	CLIMB (INCHES)	MOUNT	DAMAGE TO CAR	WHEEL CONTACT ON CURB (FT)		CURB CONTACT ON WHEEL (%)			
							FRONT	REAR	TIRE	RIM	TIRE	RIM
9	7.5	45	R	F-6		MAJOR	11.0	.5	100	10	100	10
9	15	20	R	F-2		"	10.0	6.0	75		50	
9	15	30	R	F-2		"	9.0	5.9	90	40	70	50
9	15	45			F-R	"	5.5	2.5	100	50	30	30
9	20	20	F-R			"	7.0	5.0	30	30	60	60
9	20	30			F-R	"	1.5	1.5	25	25	12	12
9	20	30 R			F-R	"	4.0	2.0	50	50	20	20
9	30	20			F-R	"	1.0	1.0	10	10	10	10
10	15	45			F-R	"	8.0	4.7	45	30	10	10
10	20	30	R	F-1		"	9.0	3.5	40	40	70	60
10	20	45			F-R	"	4.0	2.0	30	30	20	20
11	15	45	R	F-3		"	21.8	9.7	70	60	40	40
11	20	45			F-R	"	4.3	2.3	20	15	10	10
12	15	45		F-6 R-1		"	5.7	3.0	50	50	20	20
12	20	45			F-R	"	16.0	8.3	60	75	100	100

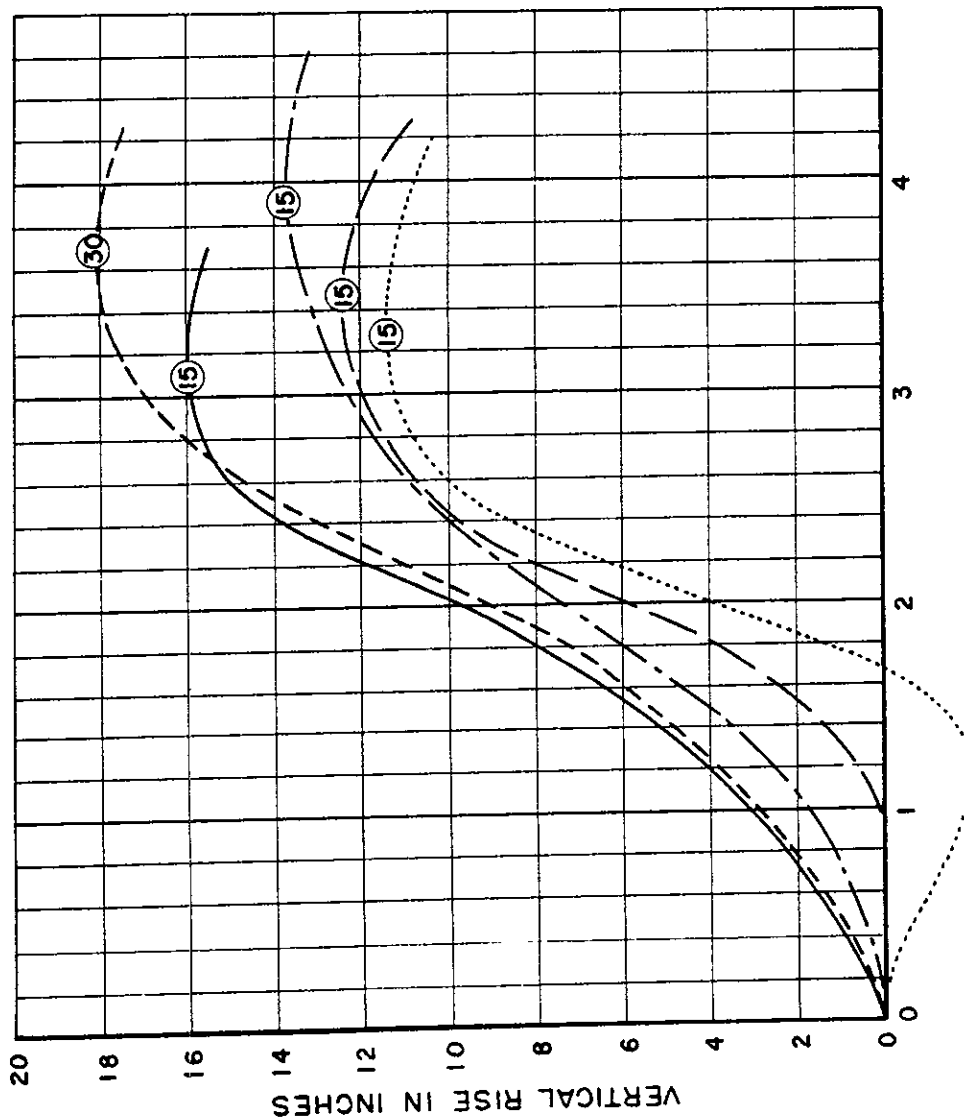
(F = Front R = Rear)

CURB C - 1955 Barrier Curb Test Data

CURB HEIGHT (INCHES)	ANGLE (DEG.)	SPEED (M/H)	DEFL. (INCHES)	CLIMB (INCHES)	MOUNT	DAMAGE TO CAR	WHEEL CONTACT ON CURB (FT)		CURB CONTACT ON WHEEL (%)			
							FRONT	REAR	FRONT		REAR	
									TIRE	RIM	TIRE	RIM
9	15	30	R	F-6		MAJOR	14.3	5.4	50	30	40	15
9	15	45			F-R	"	3.5	2.0	30	10	15	5
9	20	30			F-R	"	3.0	18.0	25	5	5	5
12	15	45			F-R	"	6.8	4.5	85	50	15	5

CURB D - 1955 Barrier Curb Test Data

(F = Front R = Rear)



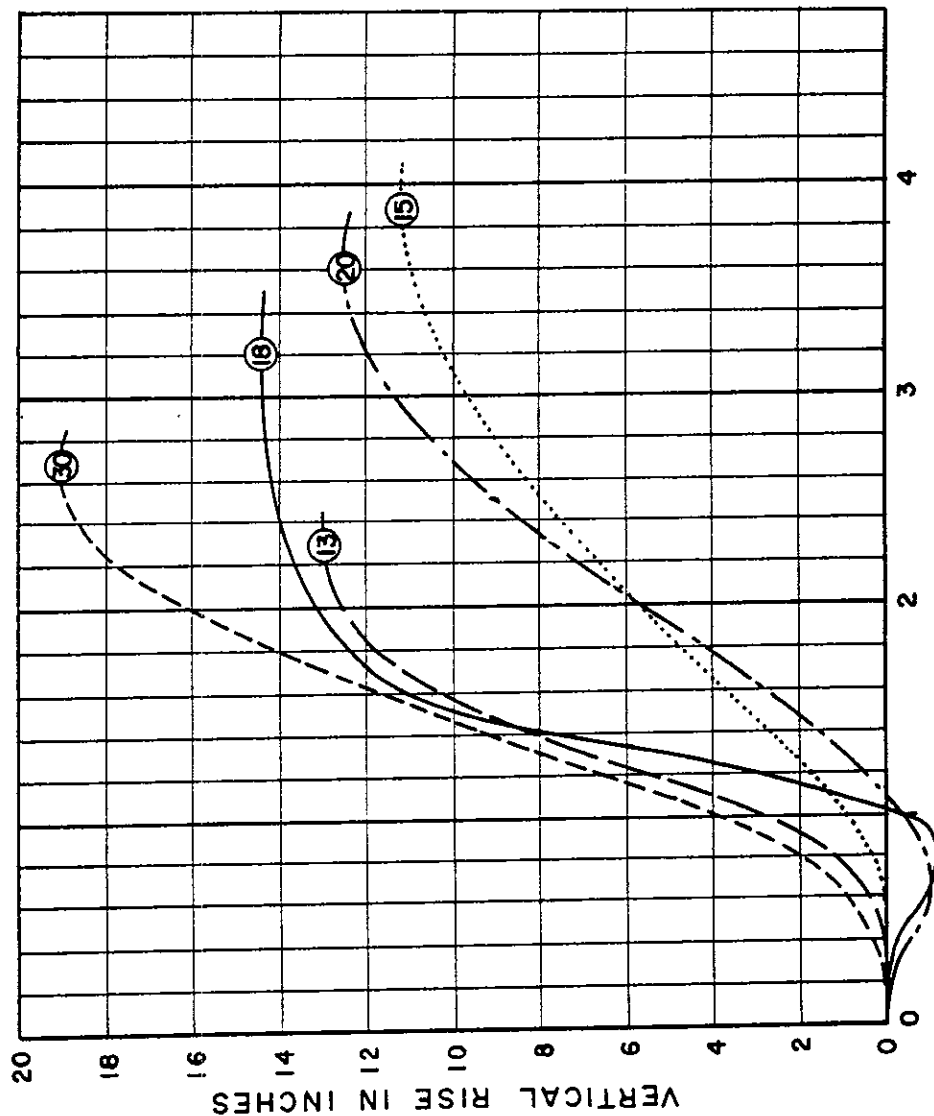
Note: Circled numbers indicate distance in feet along vehicle path from point of impact to crest of jump.  
Vertical rise is referenced to right front of car frame.

HORIZONTAL DISTANCE IN FEET  
( Horizontal Components of Vehicle Path  
Measured Perpendicular to Curb)

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STATE OF CALIFORNIA — DIVISION OF HIGHWAYS  
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Figure 14

Figure 15

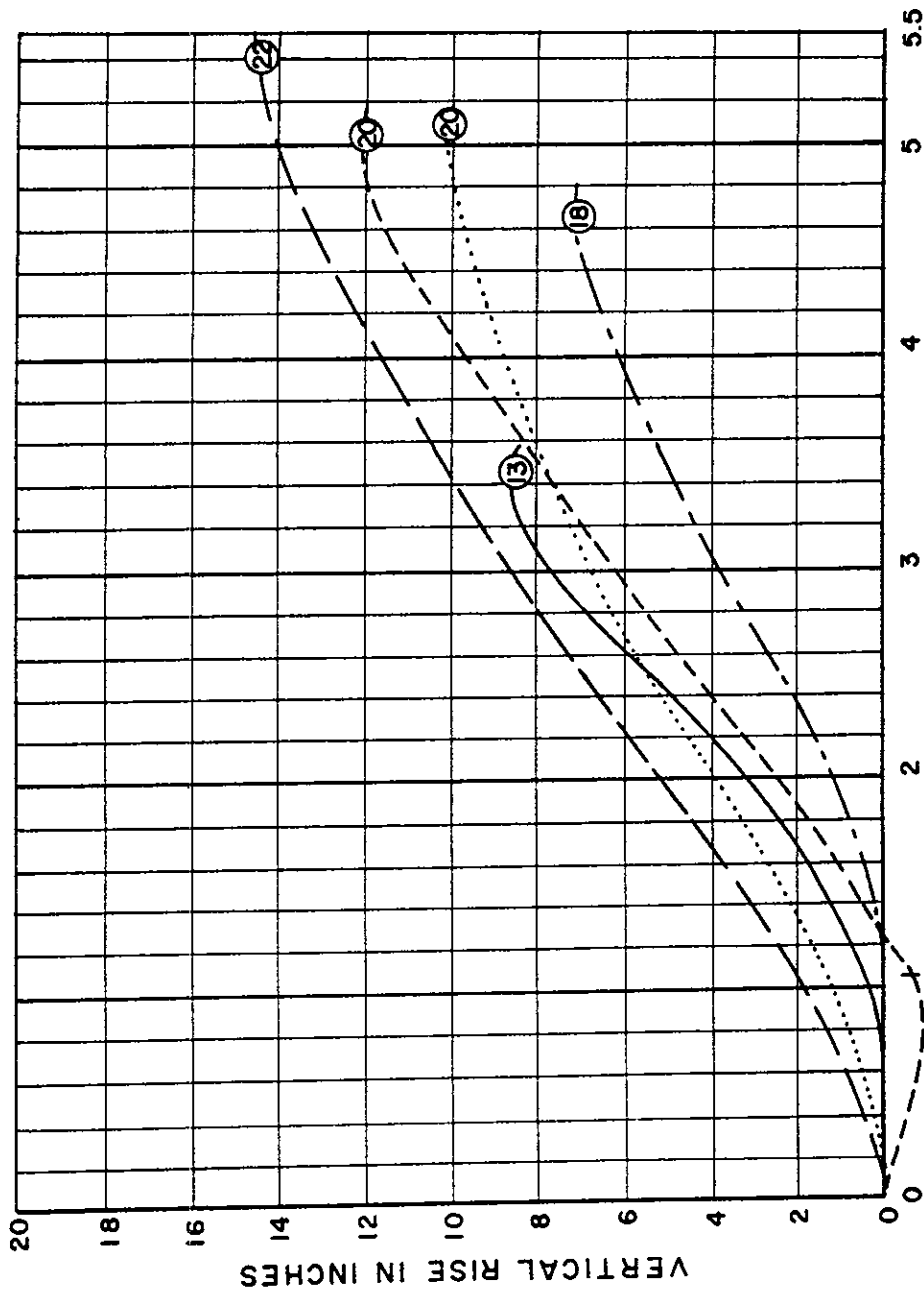


**HORIZONTAL DISTANCE IN FEET**  
(Horizontal Components of Vehicle Path  
Measured Perpendicular to Curb)

Curb	Angle	Speed	Curve
B 9	7.5°	60	---
B 9	15°	20	---
B 9	15°	30	---
B 9	20°	30	.....
B 11	15°	45	---

Note: Circled numbers indicate distance in feet along vehicle path from point of impact to crest of jump.  
Vertical rise is referenced to right front of car frame.

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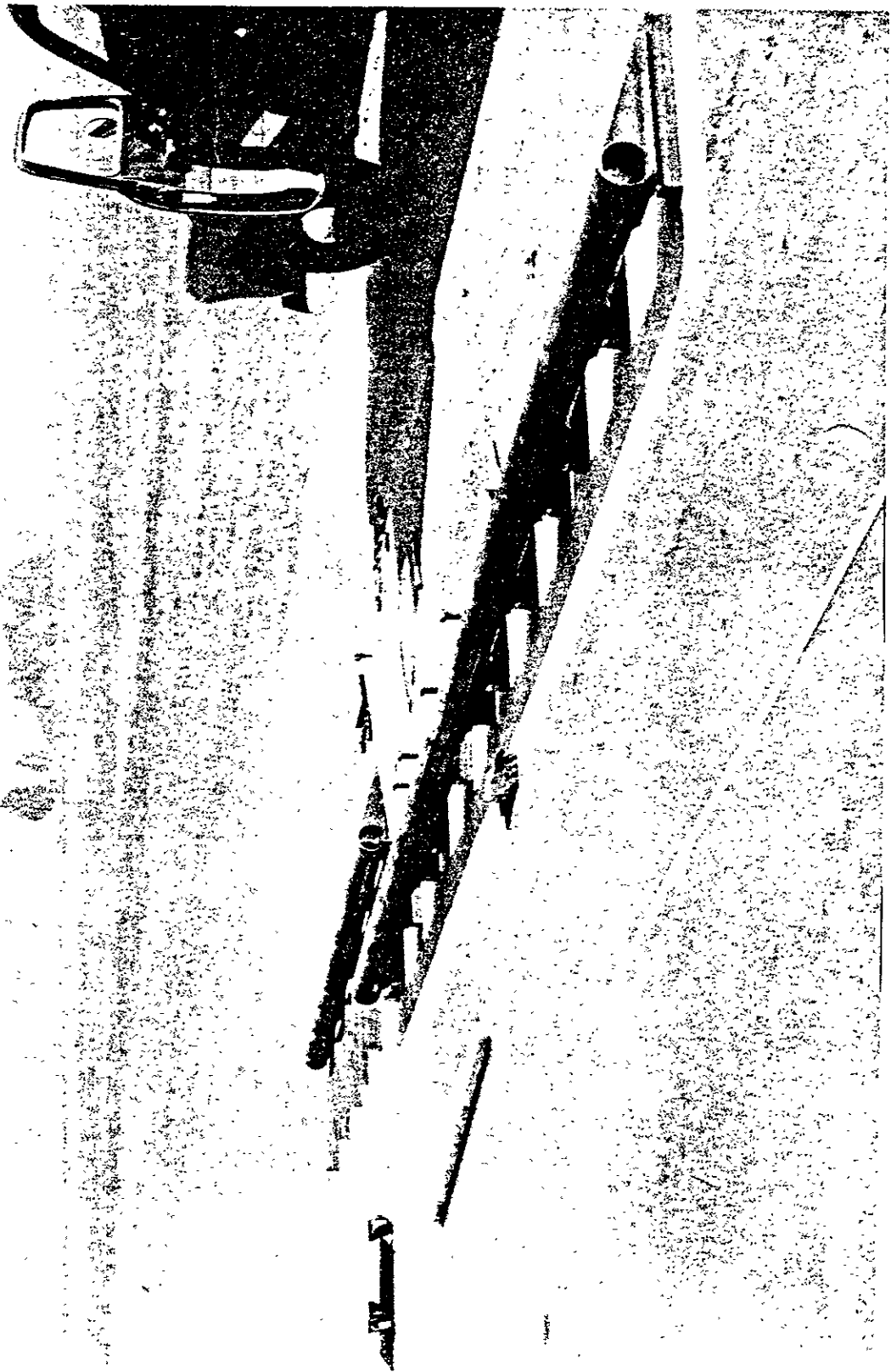
Note: Circled numbers indicate distance in feet along vehicle path from point of impact to crest of jump.  
Vertical rise is referenced to right front of car frame.

HORIZONTAL DISTANCE IN FEET  
( Horizontal Components of Vehicle Path  
Measured Perpendicular to Curb )

Figure 16

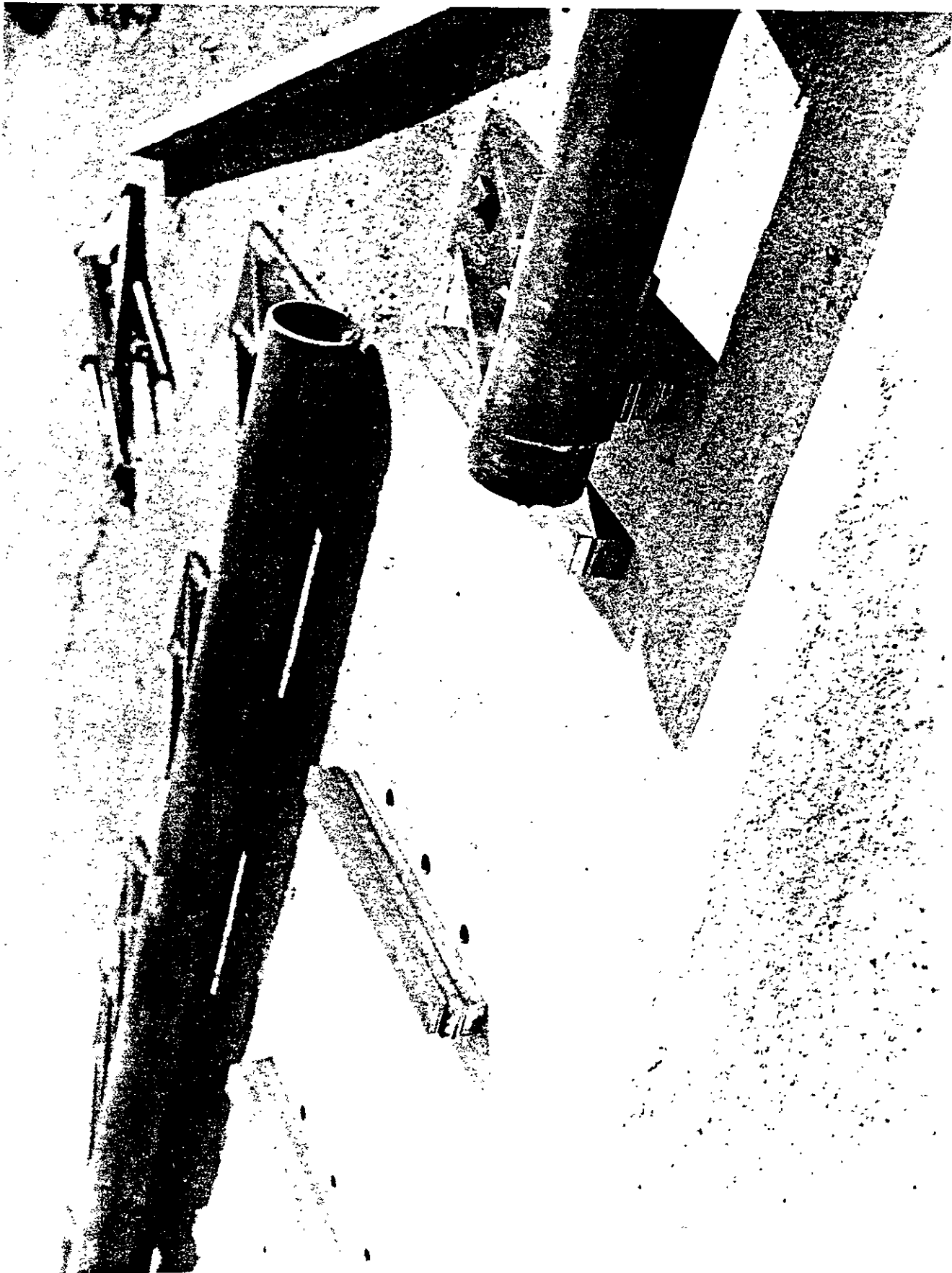
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Figure 17



General details of test curb assembly

Figure 18



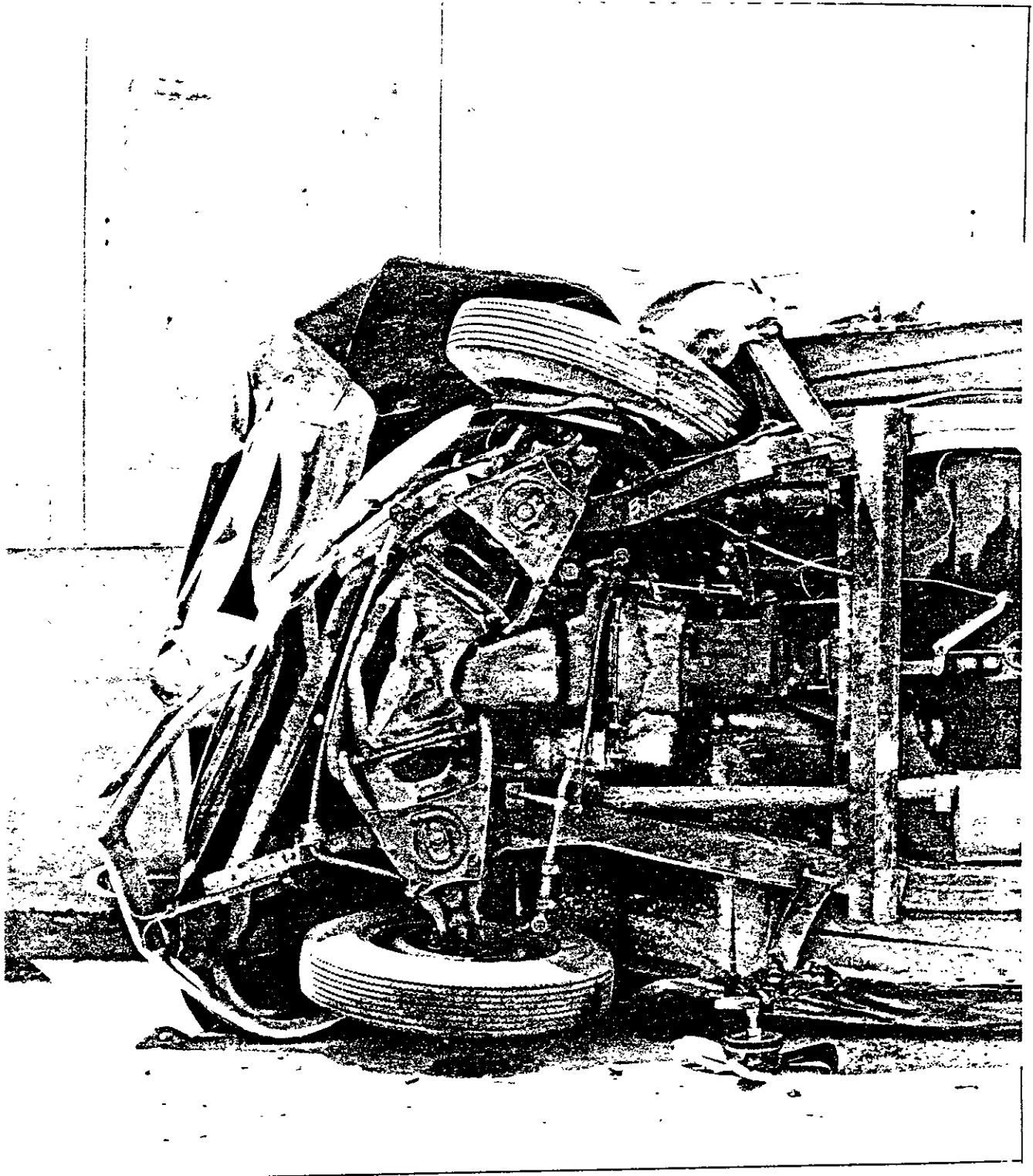
General details of test curb assembly showing concrete anchor block and adjustable shims.





Cine Film Strip Reproduction  
Note action of front wheel as it passes over curb.





View showing steel angle welded across frame and additional side plate stiffeners welded to front end of frame members.